TAUOLA the library for τ lepton decay, and KKMC/KORALB/KORALZ/... status report

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The status of the Monte Carlo programs for the simulation of the τ lepton production in high energy accelerator experiments and decay is reviewed. In particular, the status of the following packages is discussed: (i) `TAUOLA` for τ-lepton decay, (ii) `PHOTOS` for radiative corrections in decays, (iii) `KORALB, KORALZ, KKMC` packages for τ-pair production in e^+e^- collisions and (iv) universal interface of `TAUOLA` for the decay of τ-leptons produced by"any" generator. Special emphasis on requirements from new and future experiments is given. Some considerations about the software organization necessary to keep simultaneously distinct physics initializations for `TAUOLA` are also included.

1. Introduction

The `TAUOLA` package [1–4] for the simulation of τ lepton decays and `PHOTOS` [5,6] for the simulation of radiative corrections in decay, are computing projects with a rather long history. Written and maintained by well defined authors, they nonetheless migrated into a wide range of applications where they became ingredients of complicated simulation chains. As a consequence, a large number of different versions are presently in use. From the algorithmic point of view, they often differ only in a few small details, but incorporate a substantial amount of specific results from the distinct τ-lepton measurements. Such versions were mainly maintained (and will remain so maintained) by the experiments taking precision data on τ leptons. On the other hand, many new applications were developed recently, often requiring program versions which differ because of interfaces to other packages (eg. the format of the event record had to be adjusted, the organization of the input parameters changed, etc.).

In the last two years, substantial progress for the simulation of τ-pair production was achieved. Control of the systematic errors, for the theoretical predictions, at the few permille level was achieved (or, for some centre-fo-mass system energies, is relatively easy to achieve in the near future) for the centre of mass energy from the τ-pair production threshold up to the energies of the future linear colliders.

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2. Versions of TAUOLA Monte Carlo

In ref. [4] the setup for constructing specific versions of `TAUOLA` and `PHOTOS` from the single set of files was prepared and documented. The system was prepared for the software librarians and advanced users interested in updating the packages for the multipurpose environment. The idea was to create a repository which allows one to keep all main options of `TAUOLA` developed for different purposes in a relatively compact form, without duplications of semi-identical parts. The repository was set to produce the standard `FORTRAN` files which can be later handled, exactly the same way, as the published versions of the packages.

Motivations for versioning:

1. `PHOTOS`: Versions of the `FORTRAN` code are necessary because of the different versions

of the `HEPEVT` common block being in use in the HEP libraries (single/double precision, dimensionality of storage matrices).

2. `TAUOLA`: Versions of the `FORTRAN` code are motivated by: (A) different versions of initialization of physics parameters; (B) interfaces to different Monte Carlo generators for production of τ-lepton(s); and (C) different versions of the `HEPEVT` common block:
   - (A) Different physics initializations:
     (1) As published in [3];
     (2) As initialized by the ALEPH collaboration [7] (it is suggested to use this version only with the help of the collaboration's advice);
     (3) As initialized by the CLEO collaboration [8] (see the printout of this version for details);
     (4) Further coding of some individual decay modes.
   - (B) Different interfaces with MC generators:
     (1) Old demo program as in the published version [3];
     (2) Interface to `KKMC` [9];
     (3) New universal interface using `HEPEVT` common block.
   - (C) Different versions of the `HEPEVT` common block.
3. TAUOLA and PHOTOS: different versions of random number generators.
4. TAUOLA and PHOTOS: makefiles with different compiler flags.

Standard tools are used in the discussed setup: `cpp` the C-language pre-compiler: its `if`, `elif` and `include` commands, as well as `UNIX` logical links and `cat` command. The aim is to provide full backward compatibility at the level of the `FORTRAN` source with the published versions, or other versions being in use at present. It is expected that one will use the setup to create her/his version of the `TAUOLA` and `PHOTOS` libraries and interfaces (subdirectories `tauola/` and `photos/`) consisting of the plain `FORTRAN` code. The original subdirectories of the setup can then be erased or stored for future use.

The following directories are created once the actions of the setup are completed:

1. `photos/`: Standard directory with the `FORTRAN` code of the `PHOTOS` library and its demo.
2. `tauola/`: Standard directory with the `FORTRAN` code of the `TAUOLA` library, its demos and example outputs.
   (a) `tauola/demo-standalone`: Demo program for `TAUOLA` executed in a standalone mode.
   (b) `tauola/demo-jetset`: Demo program for `TAUOLA` executed with universal interface to physics event generators based on the `HEPEVT` common block. In this demo `HEPEVT` is filled from the `JETSET74` [10] Monte Carlo generator.
   (c) `tauola/demo-KK-face`: Interface to the KK Monte Carlo [9].

2.1. Options for PHOTOS Monte Carlo

The different options of `PHOTOS` which can be created[2] correspond solely to the different versions of the `HEPEVT` common block. The possible options are:

1. `KK-all` – for KK Monte Carlo
2. `2kD-all` – dimension 2000 double precision
3. `4kD-all` – dimension 4000 double precision
4. `2kR-all` – dimension 2000 single precision
5. `10kD-all` – dimension 10000 double precision

2.2. Options for TAUOLA Monte Carlo

Basic options for the physics initializations, activated with the single command `make`, are: `cpc`; `cleo`; `aleph`. The three possible versions of the created `tauola` directory correspond

[2] Executing single command: `make xxx-all`.

to form-factors and branching ratios defined respectively as in: (cpc) the published version of TAUOLA; (aleph) the conventions as adopted by the ALEPH collaboration, (cleo) the conventions as adopted by the CLEO collaboration.

• Additional parametrizations for form-factors, which can be useful in some applications, are placed in the separate directory. At present, the code used in refs. [11] and [12] is stored there.

• It is often necessary to change some of the TAUOLA input parameters like branching ratios, the mass of the τ-lepton, etc. It is convenient to have it done once for all applications i.e. demo-KK-face, demo-jetset and demo-standalone. The special arrangements to do it, in a consistent way, are provided. For details of the initialization routines, which are semi-identical in the three cases, see refs. [1–3]. Note that special care from the physics point of view is needed. Often, input parameters are inter-related with the actual choice of form factors. The changes should be thus performed simultaneously.

3. Universal interface based on HEPEVT common block

The universal interface of TAUOLA for "any" τ production generator is provided. It uses as an input, the HEPEVT common block and operates on its content only. As a demonstration example the interface is combined with the JETSET generator, however it should work in the same manner with the PYTHIA[3], HERWIG or ISAJET generators as well.

The interface work in the following way:

- The τ-lepton should be forced to be stable in the τ production generator.

- The content of the HEPEVT common block is searched for all τ leptons and neutrinos first.

- It is checked if there are τ-flavour pairs (two τ-leptons or τ-lepton and τ-neutrino) originating from the same mother.

- The decays of the τ-flavour pairs are performed with TAUOLA. Longitudinal spin effects are generated in the case of the τ produced from decay of: $W \to \tau\nu$, $Z/\gamma \to \tau\tau$, the neutral Higgs boson $H \to \tau\tau$, and the charged Higgs boson $H^{\pm} \to \tau\nu$. Parallel or anti-parallel spin configurations are generated, before calling on the τ decay, and then the decays of 100 % polarized τ's are executed.

- In the case of the Higgs boson (for the spin correlations to be generated) the identifier of the τ mother must be that of the Higgs.

- In case of the W and Z/γ it is not necessary. If from the same mother as that of the τ there is produced also a ν_τ, the W is reconstructed by the interface as the sum of the two. Simmilarily, Z/γ is reconstructed if from the same mother another τ is produced.

- Let us note that the calculation of the τ polarization created from the Z and/or virtual γ (as function of the direction) represents a rather non-trivial extension. Dedicated study of the production matrix elements of the host generator is necessary. A separate paper [13] is devoted to this point; let us show however some preliminary results in the next section. At this moment the distribution version of the package, available from the www-page, does not include this possibility. The updated version can be obtained from the authors upon individual requests only.

- Photon radiation in decay is performed with PHOTOS.

4. Tau polarization from the Z/γ mechanism

The best way of calculating spin state of any final state is with the help of the matrix element and the rigorous density matrix treatment. This is however not always possible or necessary. Often, like in the case of the production and decay

[3] It was already checked to be the case.

of particles in the ultra-relativistic limit a simplified approach can be sufficient. Such an approach was developed for KORALZ Monte Carlo program [14] and its limitations were studied with the help of matrix element calculations of order α [15]. In [13] we study the question of whether a similar approach can not be generalized, and the approximate spin correlation calculated from the information stored in the HEPEVT common block by the typical τ production program:

The approximation consists of calculating/approximating variables and later using the spin correlation of the elementary $2 \to 2$ body process $e^+e^-(q\bar{q}) \to \tau^+\tau^-$, buried inside multi-body production process. Let us stress that such a procedure can never be fully controlled as its uncertainties and even functioning depends on the way the particular production program fills the HEPEVT common block. It will be always responsibility of the user to check if in the particular case the approximation can be useful. Nonetheless our aim is *not* to replace the matrix element calculations, but rather to provide a method of calculating/estimating spin effects in cases when otherwise spin effects would not be taken care of, at all. Needless to say such an approach is limited for the spin treatment to the approximation not better than the leading-log.

The principle of calculating kinematical variables is simple. The 4-momenta of the $2 \to 2$ body process have to be found. The 4-momenta of the outcoming τ's are used directly. Initial state momenta are constructed from the incoming and outcoming momenta of the particles (or fields) accompanying production of the Z/γ state[4]. We group them accordingly to fermion number flow, and ambiguous additional particles are grouped (summed) into effective quarks to minimize their virtualities. Such an approach is consistent in the case of emission of photons or gluons with the leading log approximation.

In the following, let us give a few examples of tests we have performed so far on the elements of the calculation, see ref [13] for more details. In fig. 1 we plot the τ polarization in $2 \to 2$ body scattering as a function of the scattering angle respectively for e^-e^+, $u\bar{u}$, $d\bar{d}$ initial states. In fig. 2 we use the most spin sensitive decay mode $\tau \to \nu\pi$ and we show the π energy spectrum (in the Z rest-frame), and energy-energy correlations between π^+ and π^- (also in the Z rest-frame). Due to the Z interaction the τ leptons are polarized; there is thus a shift toward lower energies in the π energy spectrum. From the second part of the plot, we see that the configurations where both π^+ and π^- have energies bigger or smaller than average are more populous than the mixed configurations, exhibiting the vector nature of the $Z/\gamma - \tau - \tau$ vertex. On the contrary, in the case of the production from the Higgs meson, the opposite would be true, and the mixed fast-slow (slow-fast) configurations would be more common, the energy spectrum of the π would be flat.

[4]The Z/γ state does not need to be explicitly coded in the HEPEVT common block. Note that if available, information from the history part of the event, where the 4-momenta of gluons quarks etc. are stored, will be used.

5. The τ pair production in e^+e^- collisions

Until 1999 the two widely used programs for the τ-pair production in e^+e^- collisions were KORALB [16] and KORALZ [14]. The first of the two programs was used mainly at lower energies where its full treatment of spin and τ-mass effects was more important than its limited, first-order only, treatment of radiative corrections. KORALZ was more appropriate for the higher energy zone, especially on the peak of the Z resonance, where the ultra-relativistic approximation of the spin effects was sufficient, effects of the higher order QED corrections were important, and, thanks to the Z life-time, the interference of initial and final state bremsstrahlung was strongly suppressed. This second assumption turned out not to withstand the numerical requirements of the LEP2 physics see eg. [17]. Also, it is not enough for requirements of the future high energy Linear Colliders requirements such as TESLA [18].

In the recent years, a new Monte Carlo program, based on exponentiation performed at the spin amplitude level, was developed [9]. Thanks to the applied technique, it can provide predictions at the precision level of a few permille, for centre-of-mass energies from τ production threshold up to the energies of the linear collider range.

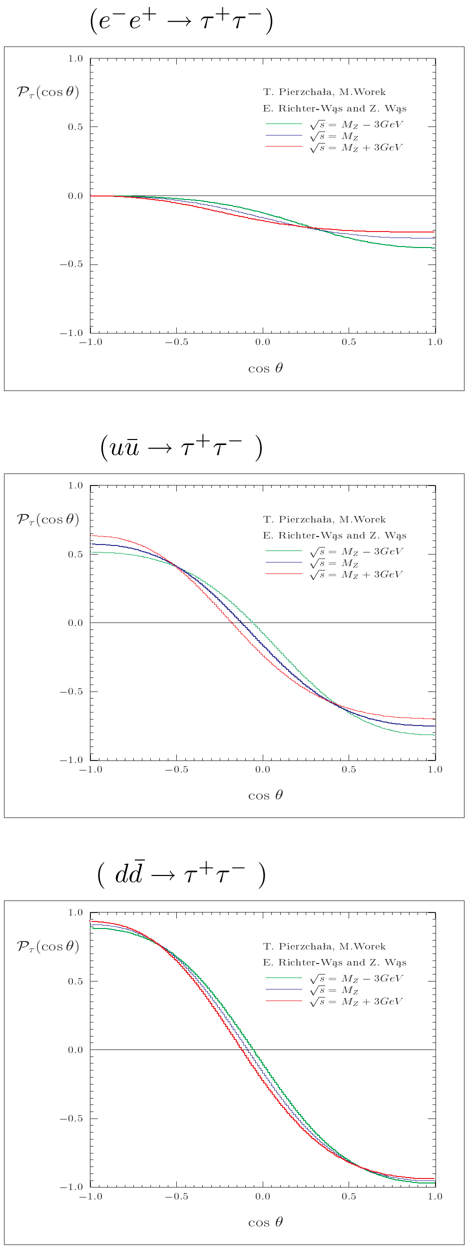

Figure 1. Tests of the `TAUOLA` universal interface. The τ lepton polarization as a function of $\cos\theta$. We have used $\sqrt{s} = M_Z$, $M_Z \pm 3$ GeV.

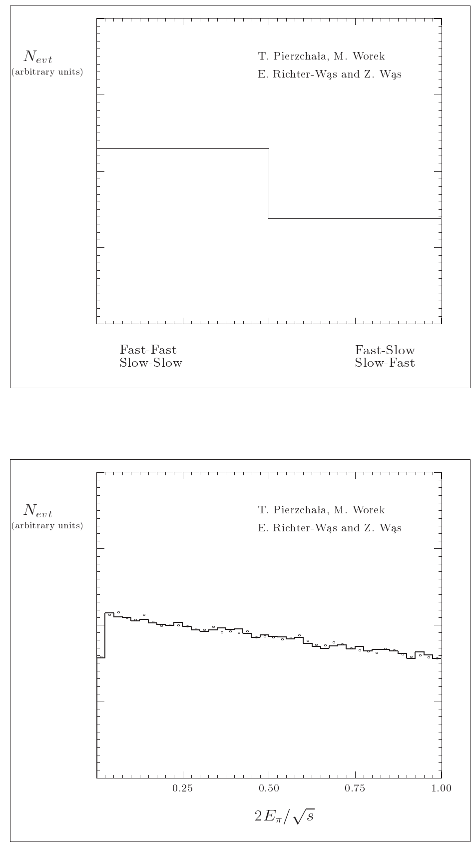

Figure 2. Tests of the `TAUOLA` universal interface, $\sqrt{s} \simeq M_Z$, spin effects included.
Lower plot: The π energy spectrum.
Upper plot: $\pi^+\pi^-$ Energy-Energy correlations.
Both plots are for energies calculated in the Z rest-frame.

So far, precision tests were performed for the centre-of-mass energies corresponding to LEP2. For other energies, points such as matching virtual pair corrections with simulations of 4-fermion final states [19], photonic vacuum polarization effects at low energies, Coulomb interactions, mass terms in some virtual corrections, etc. have to be discussed before precision at the permille level can be granted. For more details and comparisons between `KKMC`, `KORALZ` and `KORALB`, see table 1 and ref. [9].

Feature	KORALB	KORALZ	$\mathcal{KK}$ 4.13	$\mathcal{KK}$ 2000+?
QED type	$\mathcal{O}(\alpha)$	EEX	CEEX, EEX	CEEX, EEX
CEEX(ISR+FSR)	none	none	$\{\alpha, \alpha L; \alpha^2 L^2, \alpha^2 L^1\}$	$\{\ldots\alpha^2 L^1; \alpha^3 L^3\}$
EEX(ISR*FSR)	none	$\{\alpha, \alpha L, \alpha^2 L^2\}$	$\{\alpha, \alpha L, \alpha^2 L^2, \alpha^3 L^3\}$	$\{\ldots\alpha^2 L^2, \alpha^3 L^3\}$
ISR-FSR int.	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha)$	$\{\alpha, \alpha L\}_{\rm CEEX}$	$\{\alpha, \alpha L\}_{\rm CEEX}$
Exact bremss.	1 γ	1, 2coll. γ	1, 2, 3coll. γ	up to 3 γ
Electroweak	No Z-res.	DIZET 6.x	DIZET 6.x	New version?
Beam polar.	long+trans.	longit.	long+trans.	long+trans.
τ polar.	long+trans.	longit.	long+trans.	long+trans.
Hadronization	—	JETSET	JETSET	PYTHIA
τ decay	TAUOLA	TAUOLA	TAUOLA	TAUOLA
Inclusive mode	—	No	Yes	Yes
Beamstrahlung	—	No	Yes	Yes
Beam spread	—	No	Yes	Yes
$\nu\nu$ channel	—	Yes	No	Yes
ee channel	—	No	No	Yes
tt channel	—	No	No	yes?
WW channel	—	No	No	yes?

Table 1: Comparison of the main features for the `KORALB`, `KORALZ`, and `KKMC` programs, see ref. [9] for more details.

6. Summary and future possibilities

The status of the programs for the production of τ leptons was reviewed. The high precision Monte Carlo program `KKMC` for τ-pair production in e^+e^- collisions was presented. The general purpose interface, with the partial treatment of spin effects, of `TAUOLA` to any production program was also reviewed. At present, in its full content, it is available from the authors upon individual request only.

Distinct versions of the `TAUOLA` library for τ lepton decay, and of `PHOTOS` for radiative corrections in decays, are now in use. The versions differ either due to physics initialization or requirements of the interfaces. We have presented the system for creating the required version of the `PHOTOS` and `TAUOLA` packages from the single master copies. The master copies are kept in relatively compact and clear form, without code duplications and with the help of the `cpp` precompiler.

We expect that this organization, on top of the practical goals of the every day applications, may serve also as a step to develop the packages (without loss of their physics content) into new internal architectures. Some additional experience was collected in [20] in context of `OO C++`. We have found that the language translation for the given program version is relatively easy. On the contrary, the question of project continuity into further upgrades motivated by the physics needs to be thought over carefully. Matching the programming styles, e.g. of the `OO C++` experts, with the strategies of testing the numerical correctness of consecutive versions is a rather crucial issue which has to be addressed. Tools and methods embodied in `FORTRAN` survive such translations with difficulty.

The successful strategy will probably require simultaneous fluency, at a certain step of the project development, in `FORTRAN`, `OO` languages *and* the physics content of the project, by all involved persons. Platform independent tools for mixing code in `FORTRAN` and `OO` languages will be of great help.

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